

MODEL FOR WELL WATER CHLORINATION

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CERTIFICATE

Certified that the work presented in this thesis entitled 'MODEL FOR WELL WATER CHLORINATION' by Mr. Daya Shankar Ray has been carried out under my supervision and it has not been submitted elsewhere for a degree.

JULY, 1981

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MODEL FOR WELL WATER CHLORINATION

ABSTRACT

In view of the importance of providing safe drinking water through dug-well in villages, disinfection of well water is essential. A number of well water Chlorinators are described in literature which indicate that while the morphology and construction details vary, the principle involved is same. Since this process is of vital importance, the design has to be rational and modelled in accordance with the practical data..

The present study attempts to test the applicability of the few diffusion models for the diffusion of Chlorine from a pot Chlorinator in disinfecting well water. A model well is prepared at the laboratory scale to study the diffusion process. The most probable models were tried to fit in the experimental data by non-linear regression analysis. The results of model fitting indicated that the diffusion co-efficient does not remain constant through out the diffusion process. Subsequently the diffusion co-efficient was varied with concentration and a good correlation was obtained between the experimental and model predicted values. The model is able to simulate the observed spatial and temporal variations of Chlorine in the well lastly, a design criterion has been proposed to design a pot Chlorinator. A sample design procedure is given for a typical well.

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1. INTRODUCTION

This is international water supply and sanitation decade. Providing drinking water to the millions of villagers is the orderus task under taken by most of the governments across the world. India is tackling the problem by identifying the Problem Villages, which cannot easily get water either from the ground by dug wells or surface water within a couple of kilometers.

At the end of 1970, the rural population of the developing countries surveyed by W.H.O. amounted to 72 per cent of the total population of those countries. Of these rural population, 86 per cent were without reasonable access to safe water (World Health Statistics Report, 1973). India's population in March 1981 was approximately 683.8 millions, of which nearly 79 per cent were living in villages. So, construction of organised water supply schemes becomes financially difficult. Nevertheless, it is essential to ensure that most of these people get at least microbially safe if not completely treated water.

The problem of water for human consumption resolves into two main criteria. The quantity aspect and quality aspect. Either of them cannot be divorced from

important factors to be kept in mind in use of pot Chlorinators. Logical figures for quantification can be obtained only when data is available with regard to the available chlorine at average depths in a well from which water is taken by villagers. This brings further consideration of diffusion of chlorine in water. The present study attempts to test the applicability of the few diffusion models for chlorine diffusion from a pot chlorinator for well water disinfection. The most probable models were tried to fit in the experimental data by nonlinear regression analysis.

CHAPTER II

LITERATURE REVIEW

In disinfection all microorganisms including pathogenic organisms are either destroyed or inactivated. The disinfection of water is without doubt the most potent weapon used by the health and water authorities against water borne infection (Fair et.al., 1968).

2.1 PRACTICE OF DISINFECTION

Records show that boiling of water had been recommended as early as 500 B.C. There is evidence that older civilization used to store drinking water in copper and silver vessel before use (Weber, 1972). In 1825, for the first time Chlorinated lime was used to prevent the infection of wounds. In 1863, Pasteur had developed the germ theory of disease and Robert Koch, in 1881, was able to demonstrate the destruction of pure culture of bacteria by hypochlorite under controlled laboratory conditions. In 1897, Krong and Paul carried out research work which laid the foundation of modern chemical disinfection. Chick, in 1908; proposed mathematical models of disinfection. This chain continued, and till to day several people have worked in the area of disinfection and have contributed significantly to the knowledge.

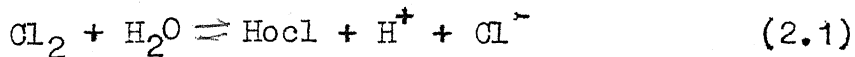
2.2 DEVELOPMENT OF CHLORINE AS DISINFECTANT

Chlorine was first used for disinfection of municipal water supply in U.S.A. in 1908. During infancy of water Chlorination, the only commercial sources of Chlorine were chlorinated lime, bleaching powder and sodium hypochlorite bleach solution. The first full scale use of liquid Chlorine for water disinfection was started in 1912 when Gillick and Huy successfully eliminated a recurring typhoid outbreak at Niagara Falls, Newyork, using solution feed equipment developed by Georg Ornstein (AWWA, 1971). Hypochlorite water Chlorination gradually decreased in popularity but it received renewed stimulus with commercial availability, in 1928, of high test calcium hypochlorite, a more stable and active material than the various bleaching powders previously available.

2.3 FREE AVAILABLE CHLORINE

The application of variety of Chlorine compounds in water treatment calls for a common basis to compare their relative content of active ingredient which is usually measured as available chlorine (Weber, 1972). Chlorine is used in the form of ~~free~~ free chlorine or as hypochlorite. In either form it acts as potent oxidising agent and often dissipates itself inside reaction so rapidly that little disinfection is accomplished until amounts in

excess of Chlorine demand have been added (Sawyer and McCarty, 1967). When Chlorine is added to chemically pure water, a mixture of hypochlorous and hydrochloric acid is formed.



the hydrolysis constant K_H is 4.48×10^{-4} moles/lit at 25°C .

At ordinary temperature, the reaction completes within few seconds. In dilute solution and at pH levels above 4, the equilibrium is displaced towards right and very little Chlorine exists in solution. The oxidising properties of the chlorine are retained in the HOCl formed and it is with this form the principal disinfecting action of Chlorine solution is associated (Morris, 1946).

The hypochlorous acid formed is a weak acid and is very poorly dissociated at pH levels below 6. The degree of dissociation depends on pH and temperature.



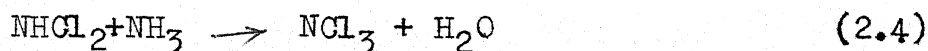
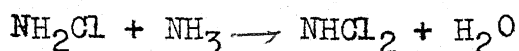
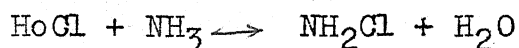
The ionisation constant K_i is 2.7×10^{-8} moles/lit at 20°C . Between pH of 6.0 to 8.5, there occurs a very sharp change from undissociated HOCl to almost complete dissociation. At 20°C , at a pH of about 7.5 hypochlorite ion predominates and exists almost exclusively at pH around 9.5 and above.

The chlorine existing in water as HOCl , oCl^- is defined as free available Chlorine (Morris, 1946). The bactericidal efficiency for HOCl and oCl^- is approximately 80:1 under the same condition test (Fair et.al. 1968).

2.4 COMBINED AVAILABLE CHLORINE

The most important and undoubtedly the most complex Chemistry of water and waste water chlorination is its reaction with various forms of nitrogen naturally occurring in water. If there are no nitrogeneous compounds present in water, probably there would not have any trouble of tests and odour due to Chlorination. Further, there would not have been any problem of the quantitative differentiation of Chlorine as most of the Chlorine applied would have been in the free form (White, 1972).

Chlorine in aqueous solution reacts with ammonia in following manner (Griffin and Chamberlin, 1941).



As a result of these reactions, with increasing dose of chlorine applied, there is a sudden loss of free chlorine with simultaneous disappearance of ammonia. This

observation led many investigators to the discovery of break point chlorination which ultimately gave the modern concept of Chlorination (Morris, 1946).

2.5 FREE RESIDUAL CHLORINE

Free residual Chlorine is readily obtained with water of low Chlorine demand, or may be accomplished by Chlorination beyond the breakpoint for water, containing significant quantity of reducing contamination. Chlorine demand may be exerted by a number of substances including both inorganic (i.g. H_2S , Mn^{+2} , Fe^{+2} , NH_3) and organic species (e.g. phenols, aminoacids, carbohydrates and Proteins). The maintenance of free chlorine in water supply is to prevent the future contamination (Weber, 1972).

2.6 WELL WATER CHLORINATION

Bleaching powder, potassium permagnate were generally employed as disinfectants for well water Chlorination in old days. No uniform procedure was used suspension of disinfectants were generally thrown into the well by Block health employees in monsoon or during out-break of epidemics. So, for the first instant, the residual Chlorine was so high that water gave undesirable taste and deminished so fast that water needed dissinfaction only after few days.

2.6.1 Pot Chlorination:

The first work was done by Zdravkov (1959) on continuous disinfection of well water. He used porous earthen vessels made from Potter's clay and containing bleaching powder. He called this vessel a 'Chlorine Cartridge'. He claimed that the pores of these vessels allowed sufficient chlorine to diffuse to disinfect the well waters continuously for about a month. (Patil and Rao (1964)) showed that the pores of earthen pots recommended by Zdravkov did not work satisfactorily.

(a) Cylindrical concrete Pot: Patil and Rao (1964) carried out the experiment using cement concrete cylindrical pots. Pots had been made using different proportion of sand, cement and water. After placing the calculated amount of bleaching powder in pots and lowering in to the well, it was observed that some pots were very porous and allowed all chlorine to diffuse in very short time, while others were much less porous to allow sufficient chlorine to pass out.

(b) Earthen-pot: Afterwards, earthen pots were used for their suitability for this purpose. Since they are cheap and easily available (Patil and Rao, 1964). Only traces of Chlorine were detected in the vicinity of the pot for

a very short period. Hence efforts were made to increase the porosity of these pots. Clay was mixed with different amount of combustible matter such as sawdust. But it was possible to mould only pots having thick wall so special type of clay i.e. China clay was used. But, again, only traces of residual chlorine could be detected in their vicinity. It was found that pores were completely blocked.

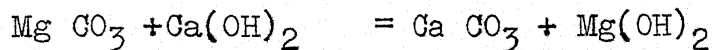
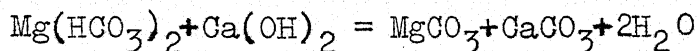
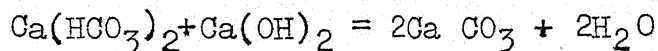
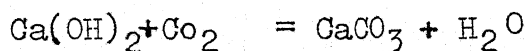
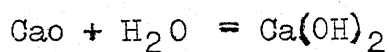
Then, Patil and Rao (1964) dealt the problem in an entirely different way. Two holes of 0.2 cm. diameter were made in top half of the vessel in ordinary earthen pot. The concentration was found to decrease to trace only in 4 days. It was found that holes were blocked and bleaching powder formed a hard mass at the bottom of pots.

Then, only one hole of diameter 0.5 cm was made to avoid blockage. Coarse sand was mixed with bleaching powder in ratio of 3:1 to avoid hard mass formation. The residual Chlorine was observed upto 11 days and hole was blocked again. After clearing the hole, the effective residual were found for another six days. Again hole was cleaned and pot was lowered into the well, but no Chlorine diffusion was observed.

2.6.2 Two Pot System:

Patil and Rao (1964) tried two pot system for well water disinfection. It was hoped that inner pot when charged with bleaching powder, work as deposit giving out chlorine in a gradual manner to the outer pot for diffusion into the well. It was thought that even if the holes of the inner pot were blocked after some time, the chlorine solution of the outer pot would diffuse for a longer time. Two small pots were used, but effective Chlorine concentration were obtained for a period of 15 days continuously. The holes of inner pot were blocked where as the holes of outer pot were opened. The holes were cleaned. The Chlorine concentration was found 6 days more.

The white material, which blocked the holes during experiment, was analysed and found mostly calcium carbonate. Magnesium compounds were also detected in small quantity. This was explained as follow:



The same authors, later on, modified the above system by placing the inner pot with respect to outer pot. The holes dimension were 1 cm. diameter. The effective Chlorine concentration were observed for 32 days and holes were blocked. The holes were cleaned from both pots. The concentration of Chlorine within outer pot was 600 mg/lit, but it no diffusion was reported.

Phadke et.al. (1967) had conducted the experiment on the basis of Patil and Rao (1964) two pot modified cartridge. The experiment was carried out with two holes of 1.25 cm diameter, each was drilled on outer pot of the cartridge. The effective chlorine was detected upto 48 days when the bleaching powder was doubled of calculated quantity. When only calculated amount of bleaching powder was used, the effective residual chlorine was detected upto 20 days.

Seth and Sukla (1972) had taken a chlorine cartridge with hole of 11/16'' at bottom and two holes of 1/4'' at top. Two tubes were fitted in the holes from which water would come in pot. Coarse sand was put in bottom of pot. Fine sand passed through sieve no. 25 and retained on sieve no. 100 was kept on coarse sand and bleaching powder paste was put on the fine sand. Chlorine was increased in first two days and later on, it was almost constant for 16 days, then, decreased to zero in about 20 days.

Prasad and Iyer (1979) tried single earthen pot with holes at bottom of Chlorine cartridge as suggested by Seth and Sukla (1972). A single pot with 8 holes of 6 mm diameter at the bottom was specially got prepared for this purpose. Half kg. of bleaching powder mixed with 3 kg. of sand was spread over a layer of corase aggregate in the pot. Another layer of coarse aggregate was laid over this mixture upto the neck of the pot. The mouth of pot was opened and suspended into the well by rope at a depth of about 30 cm below the water level.

At the same time, 0.6 litre polythene container with 6 mm diameter holes at bottom was obtained as above experiment. A thin layer of sand (passing through sieve no. 25 and retained on sieve no. 100) was spread up to $1/3$ depth of container. Half kg. bleaching powder was spread over that. The container was closed with a lid through which two 6 mm diameter glass tube were inserted. The pot was lowered at 30 cm depth. The performance of single earthen pot was better than polythene container. It was observed that some bleaching powder remained in the pot in the form of lumps. The lumps were main reason for the poor performance of polythene container. Thus, it was decided to apply bleaching powder in combination with sand to prevent the formation of

lumps. When the pot was taken out, no bleaching powder was remained in pot. As the bleaching powder was getting diffused faster through the pot giving higher value of residual Chlorine in the well. It was felt that 8 holes at bottom are not required. So, 50 per cent of the holes were plugged for next stage of experiment in both container. Dry mixture of 3 kg. of sand and 1.5 kg. of bleaching powder was placed over a layer of coarse aggregate in both container. Coarse aggregate was filled up to the neck of container and suspended into the wells of same characteristics. The performance of polythene container was much better than earthen pot.

Diffusion of HOCl and OCl^- from pot in to the well is given in Chapter III.

CHAPTER III

AVAILABLE DIFFUSION MODELS

3.1 DIFFUSION

Diffusion is a process which leads to an equilization of concentrations. The matter is transported from one part of a system to another part as a result of random molecular motions. Rich (1961) developed the mechanism of diffusion based on molecular transfer theory which is based on a physical model in which two fictitious films exist at the liquid interface at the opening. The films are considered to be stagnant and furnish all resistance to Chlorine transfer. They are assumed to be persisting regardless the magnitude turbulence in the outer water bulk. The turbulence serves only to reduce the film thickness. Bleaching powder reacts with water and yields HOCl and OCl^- in pot. At the liquid interface at the opening of the pot, HOCl and OCl^- are transported to the outer face of liquid film. HOCl and OCl^- are transported to the outerside of liquid film. HOCl and OCl^- then diffuse through this outer stagnant film to the boundary between the film and the water bulk, from where it is transported throughout the bulk liquid by concentration gradient and

mixing. Molecules move in response to the gradient from a region of high concentration to those of low concentration. This behaviour is called Molecular diffusion.

3.2 MATHEMATICAL THEORY

Fick (1855) first put the diffusion on quantitative basis by adopting the mathematical equation of heat conduction derived by Fourier (1822). The mathematical theory of diffusion is based on the hypothesis that the rate of transfer of diffusing substance through unit area of cross section is proportional to the concentration gradient measured normal to the section, i.e.,

$$F = - D \frac{\partial C}{\partial x} \quad (3.1)$$

where, F is the rate of transfer per unit area of section, C is the concentration of diffusing substance, x is the space co-ordinate measured normal to the section and D is diffusion co-efficient. Diffusion coefficient can reasonably be taken as constant in dilute solution, while in others, i.e. diffusion in higher polymers, it depends very markedly on concentration. The dimension of D , diffusion co-efficient, is $(\text{length})^2(\text{time})^{-1}$. The negative sign in equation (3.1) arises because diffusion occurs in direction opposite to that of increasing concentration.

D is independent of the unit by which the amount of substance in F and C are measured.

The fundamental differential equation of diffusion in an isotropic medium is derived from equation (3.1),

$$\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2} \quad (3.2)$$

which is Ficks second law of diffusion, derived on assumption that D is constant for one system of diffusion. For three dimensional case in isotropic medium,

$$\frac{\partial C}{\partial t} = D \left(\frac{\partial^2 C}{\partial x^2} + \frac{\partial^2 C}{\partial y^2} + \frac{\partial^2 C}{\partial z^2} \right) \quad (3.3)$$

If D depends on concentration, the equation will be

$$\frac{\partial C}{\partial t} = \frac{\partial}{\partial x} \left(D \frac{\partial C}{\partial x} \right) \quad (3.4)$$

3.3 AVAILABLE MODELS

Fick's law (3.1 and 3.2) are fundamental equations of diffusion. These equations have been solved by Crank (1975), Jost (1965) Carslow and Jaiger (1959) and Skelland (1974) considering various initial and boundary conditions. For well water Chlorination, the probable models are given here. It is very difficult to get the exact solution of Fick's low for diffusion in well. Each model has some assumptions and some initial and boundary conditions which

are not applicable to well diffusion.

- A) If we have semi infinite cylinder extending over a region $x > 0$ and with an impermeable boundary at $x = 0$, then all diffusion occurs in one direction. The amount of substance, S deposited in the plane $x = 0$. The initial conditions are:

$$C = C_0 \text{ at } x = 0 \text{ and } t = 0$$

$$C = 0 \text{ at } x > 0 \text{ and } t = 0$$

The concentration distribution for the semi infinite cylinder is given by

$$C = \frac{S}{\sqrt{\pi Dt}} \exp \frac{-x^2}{4Dt} \quad (3.5)$$

where C is concentration at any linear distance x and time t ,
 S is total diffusing substance in mg/cm^2 .
 D is diffusion co-efficient considered constant for one diffusion system.

In this solution, diffusing substance is kept uniform in total cross section of the cylinder and substance is diffused in one direction without mixing where as actual well may be considered as semiinfinite but it is difficult to keep the diffusing substance in whole cross section.

B) The concentration at distance r from a point source on an infinite plane surface is given by

$$C = \frac{S}{4\sqrt{\pi Dt}} \exp - \frac{r^2}{4Dt} \quad (3.6)$$

where, r is radial distance

Substance is instantaneous point source at origin $r = 0$.

The initial conditions are same as above. The boundary is reflecting i.e. there is no sink. Diffusion co-efficient is assumed as constant for most of the practical purposes and independent of concentration. In well water Chlorination, concentration changes very rapidly and diffusion co-efficient may not be constant. This model is given for infinite, but well is considered to be semifinite. For well water Chlorination a pot is used in water bleaching powder and sand is uniformly distributed.

C) If the diffusing substance is initially distributed uniformly through a sphere of radius 'a', the concentration at radius r and time t is given by

$$C = \frac{1}{2} C_0 \left\{ \operatorname{erf} \frac{a+r}{2\sqrt{Dt}} + \operatorname{erf} \frac{a-r}{2\sqrt{Dt}} \right\} - \frac{C_0}{r} \sqrt{\frac{Dt}{\pi}} \left[\exp - \left\{ \frac{(a-r)^2}{4Dt} \right\} \right. \\ \left. - \exp - \left\{ \frac{(a+r)^2}{4Dt} \right\} \right] \quad (3.7)$$

$$\text{Here } C_0 = \frac{S}{4/3\pi r^3} \quad (3.8)$$

Initial conditions are same as above. Solution (3.9) is also applicable for infinite case and D is assumed as constant through out the diffusion process.

D) Continuous sources: If diffusing substance is present in high concentration i.e. above saturation value, the source will act as continuous source for some time. The diffusing substance is liberated continuously from a point in an infinite volume at a constant rate. The concentration at a point r from the source at time t is given by

$$C = \frac{q}{4\pi Dr} \operatorname{erfc} \frac{r}{2\sqrt{Dt}} \quad (3.9)$$

where, q is constant rate.

Wauger (1952) and Stokes (1952) had given solution for concentration dependent diffusion coefficient. But their boundary conditions are different.

CHAPTER IV

MATERIALS AND METHODS

4.1 MATERIALS

Commercially available bleaching powder used for experiment had 300 mg/gram as available Chlorine. It was stored at low temperature to prevent loss of Chlorine.

The sand which was mixed with bleaching powder was free from organic materials, dust and the finer and coarser particles. The bulk of sand passing through Sieve No. 600 and retained on Sieve No. 500 was used.

Tap water, campus water supply, I.I.T. Kanpur, was used for experiments. The average characteristics of tap water are tabulated in Table 4.1.

TABLE 4.1
Tap Water Composition used for Experiments

Sl. No.	Composition	Value
1.	pH	8.1
2.	Free residual Chlorine	Nil
3.	Chlorine demand	1.1 mg/lit.
4.	Alkalinity	325 mg/lit as CaCO_3
5.	Hardness	240 mg/lit as CaCO_3

All chemical used were of analytical grade.

4.2 METHODS

4.2.1 Experimental Technique:

(i) Preparation of experimental well

A cylindrical plastic bucket of 40 lit capacity was chosen to represent dug well with arrangement shown in Fig. 4.1. The diameter of plastic bucket was 380 mm and height was 470 mm. A 25 mm hole was made just above 30 mm from bottom and 8 mm diameter plastic tube was fitted in the hole. For convenience of adding water a funnel was fitted in one end of the tube.

The bucket was covered with perspex sheet of 5 mm thickness with provision of one central hole, 8 holes at a radius 80 mm, 8 holes at radius of 160 mm from centre of 10 mm diameter.

10 mm diameter glass tubes were used for drawing samples from different depths. The tubes were T-shaped and nearly of 1000 mm length as shown in Fig. 4.1.

(ii) Sampler:

A sampler, design and made, was used to collect the sample through glass tubes. With 150 cc capacity bulb, the elongated end was connected with 120 mm rubber tube and other end was connected with 160 mm long glass tube with the help of cork.

(iii) Chlorinator Pot:

In the present work, a table tennis boll of 35 mm diameter and 22.45 cc volume was used to represent the pot Chlorinator. A hole of 10 mm diameter was made on the surface of pot. A small rubber cork with glass tube was tightly fitted in hole. Pin holes of 1 mm diameter (approx.) were made on half surface of the pot.

(iv) Bleaching Powder Dose:

Calculation of bleaching powder required was based on percentage available Chlorine in bleaching powder, the amount of water to be disinfected, Chlorine demand, free residual chlorine and compensate for dissipation.

$$\text{Bleaching powder required} = \frac{100}{P} [Qxl + QwXLXt + QXtXm + QXn + QwXtXn]$$

where Q is the total volume of water, Qw is withdrawal per day, l is Chlorine demand, m is compensate for dissipation, t is time for which water to be disinfected, n is residual Chlorine required and P is percentage available Chlorine. For present work, Q, Qw, P, l, m, n were taken as 40 lit, 3 lit, 30 per cent, 1.1 mg/lit, 1 mg/lit and 0.5 mg/lit respectively.

(v) Mixing of Bleaching Powder and Sand

Equal amount of bleaching powder were placed on dry papers. Sand was mixed with bleaching powder in ratio of 3.1 by volume in absolutely same condition to prevent the unequal loss. One was put in Chlorinator and other was used to monitor the initial concentration.

(vi) Experimental Set-up

Experimental well, after filling with water below a level of 85 mm from top, was covered by perspex sheet. The glass tubes were marked at length 85 to, 85 + 100, 85+200, 85 + 300 and 85+ 400 (actual depth from ball were 0, 100, 200, 300 and 400 mm) with a piece of rubber tubes. Glass tubes were arranged in both 30 mm and 160 mm radius at different depth i.e. 0, 100, 200, 300 and 400. Tubes were closed at the top. Calculated amount of bleaching powder and sand mixture were placed in the Chlorinator.

(vii) Sampling

100 ml sample were drawn twice a day from each tube with the help of sampler and were analysed for free residual Chlorine. At the same time, same amount of water was added into the experimental well without disturbing water.

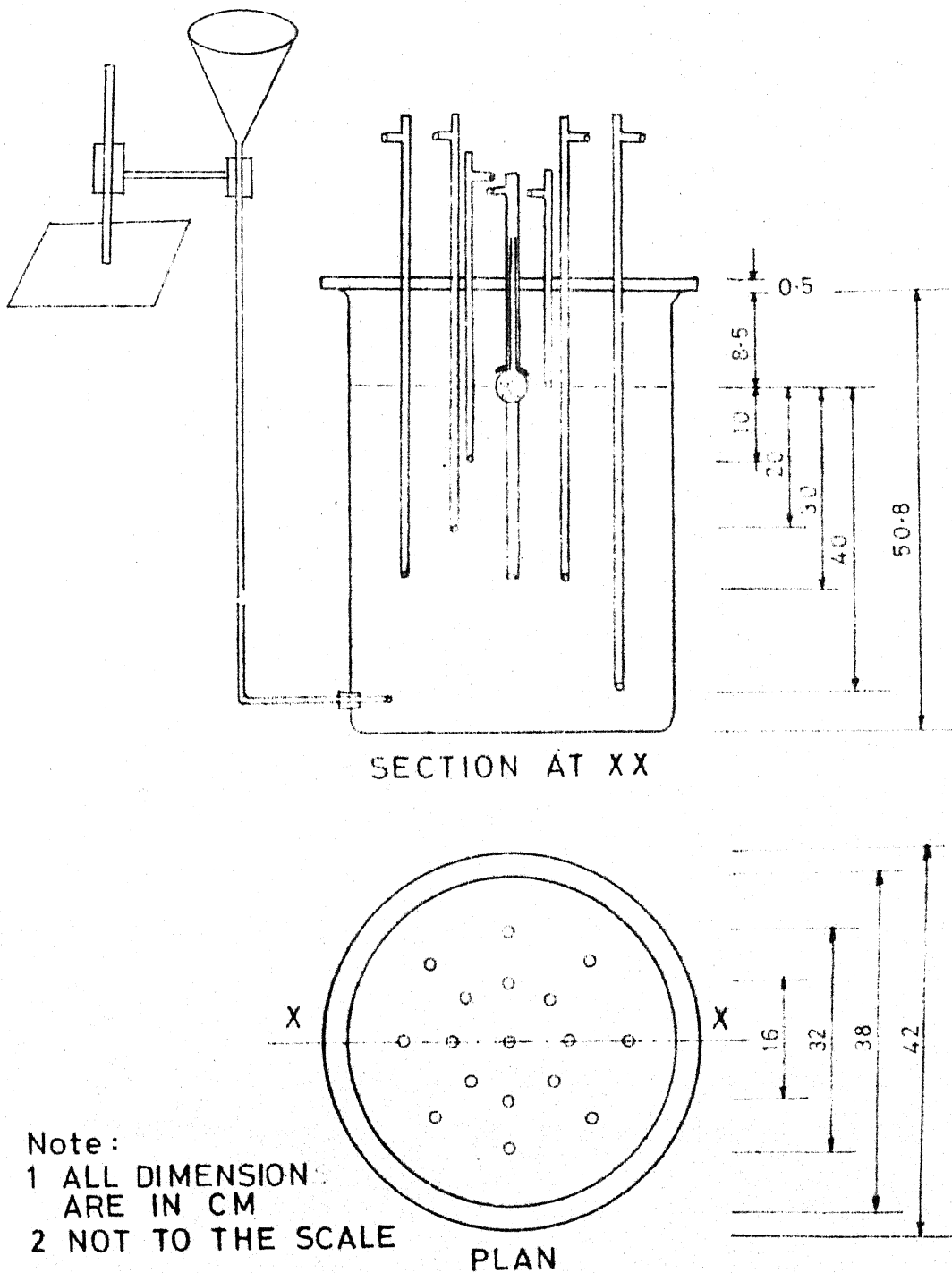


Fig.4-1 Experimental set-up

4.2.2 Analytical Technique:

- (i) Average water characteristics i.e. pH, Chlorine demand, alkalinity and hardness were monitored as per Standard Method (1975).
- (ii) Determination of available Chlorine in bleaching powder.

A sample, mixture of bleaching powder and sand (Article 4.2.1 VI) was taken in one lit of volumetric flask and suspension was made. It was allowed to settle for 10 to 15 minutes. The strength was monitored in the supernatant after proper dilution.

- (iii) Determination of Saturation value of Chlorine.

0.3, 0.5, 0.75, 1.0, 2.0 and 3.0 gram bleaching powder were taken in five volumetric flask and Chlorine was measured after proper dilution by DPD ferrous titration method as per Standard Method (1975).

Residual Chlorine Determination

Free residual Chlorine was measured by DPD ferrous titrimetric method as per Standard Method (14th Ed.)

(A) REAGENTS

- (i) Phosphate buffer:

24 grams anhydrous disodium hydrogen phosphate and 46 grams anhydrous potassium dihydrogen

phosphate were dissolved in distilled water and 800 mg EDTA was added in it and made it 1 lit.

(ii) DPD indicator solution - 1.5 gram P. amino N.N. diethylamine Sulphate was dissolved in Chlorine free distilled water. 8 ml (1+3) H_2SO_4 and 200 mg EDTA were also added and made up it 1 lit. It was stored in brown glass stoppered bottle.

(iii) Standard ferrous ammonium sulfate:

1.106 gram Mohr's salt $\text{Fe}(\text{NH}_4)_2 (\text{SO}_4)_2 \cdot 6\text{H}_2\text{O}$ was dissolved in distilled water. 1 ml. of (1+3) H_2SO_4 was added and made up it 1 lit.

(B) PROCEDURE:

5 ml. phosphate buffer and 5 ml DPD indicator were mixed together and 100 ml sample was added in it. It was titrated against Standard FAS Solution.

Residual Chlorine, mg/lit = ml of FAS titrant used.

CHAPTER V

MODEL CALIBRATION AND VERIFICATION

This work was carried in three steps. The first step was the preparation of the experimental well and monitoring the spatial and temporal variation of residual Chlorine in the experimental well. The second step was the investigation of a diffusion model which could confirm the Chlorine diffusion in the experimental well. The third step was the design of chlorinator based on selected diffusion model.

The model Chlorinator used in experimental well was designed based on Prasad and Iyer (1979) work. Nine holes of approximately 1 mm diameter were made in model Chlorinator to ensure no obstruction in diffusion.

Experiments with laboratory model well were carried out four different time periods during summer. The laboratory temperature varied slightly in 3 sets of experiments and one set was at lower temperature. The details of temperature, the initial concentration of available Chlorine from bleaching powder at the number of days are given in Table 5.1.

TABLE 5.1

Details of Temperature, Initial Concentration and Number of Days

	Room Temperature	Initial concentration (mg)	Maximum no. of days of positive test for residual Chlorine (days)
1st Set	41 ^o C	190	10.5
2nd Set	41 ^o C	180	10.5
3rd Set	45 ^o C	290	13.5
4th Set	31 ^o C	121	12.5

5.1 MODEL CALIBRATION

Various models for diffusion are given in Chapter 3. In all models, it was assumed that diffusion co-efficient (D) was constant throughout the experiment in particular set. Diffusion co-efficient was calculated by fitting the selected model to the experimental using Least Square Technique. Marquorlt (Besolve REGRESSION ALGORITHM) is used to solve the co-efficient in a non-linear regression equation (Kuester and Mize, 1973). Some typical experimental and model predicted values are given in table 5.2. The value of diffusion coefficient was $77.41 \text{ cm}^2/\text{day}$.

TABLE 5.2

Some Typical Experimental and Model Predicted Values

Day X_1	Radial distance (cm) X_2	Experimental value Y_{Expt} (mg/l)	Model predic- ted value $Y_{\text{Calculated}}$ (mg/l)	Residual (mg/l)
1.5	8	2.3	1.89	0.409
1.5	12.8	2.3	1.52	0.775
1.5	16.0	2.3	1.25	1.0497
1.5	18.87	2.3	1.00	1.2919
1.5	21.54	2.2	0.7989	1.401
1.5	25.61	2.2	0.5284	1.6715
1.5	31.05	2.2	0.2722	1.9277
1.5	34.0	2.1	0.18	1.9199
1.5	40.79	2.1	0.06	2.0395
1.5	43.08	2.0	0.0399	1.6901

Standard Error Estimate = 1.04

Co-efficient of Correlation = 0.4889

The result presented Table 5.2 show the high Standard Error Estimate and low Co-efficient of Correlation. The model predicted value didnot agree with the experimental data. It was clear that one diffusion co-efficient was not sufficient to govern the whole process. So, diffusion co-efficient was dependent on concentration remaining in the pot at that time, where as basic assumption of this model was constant diffusion co-efficient. Other models also have same assumption. So, they were not suitable for present experimental data. Other sets of experiments were not tried because all had almost same pattern.

It was difficult to get the algebric solution of Fick's law for concentration dependent diffusion co-efficient. Wanger (1952) and Stokes (1952) have given the exponential and linear solutions for calculating the concentration dependent diffusion co-efficient. But their initial and boundary condition are different.

After that the problem had been dealt in entirely different way. It was clear from the experiment that there are no sharp change in concentration in 12 hours indicating that diffusion coefficient was more or less constant for that period. So, diffusion co-efficient were calculated after each 0.5 day. Total amount of available Chlorine remaining

in the pot after each 0.5 day interval was also calculated. Using eqn. (3.6), residual Chlorine were calculated assuming diffusion co-efficient to be constant for 0.5 day and using source concentration as calculated by Computer at that time. The experimental and model predicted values for each set of experiments have been given in Figs. 5.1, 5.2, 5.3, and 5.4. Each Figure has contained only 1, 3, 5, 7 and 11 days experimental and model predicted value to prevent crowding of points. The Figures show that there is good co-relation and less standard Error Estimate between experimental and model predicted value. Taking Fig. 5.4, the Standard Error Estimate was 0.12 to 0.01 and Coefficient of Co-rrelation varied between 0.9525 to 0.7598. The variation of D were 7782 to $25.2 \text{ cm}^2/\text{day}$. Since diffusion co-efficient was dependent on concentration remaining in model Chlorinator, the diffusion Co-efficient was Co-rrelated to concentration in pot. Fig. 5.5 shows the curve between diffusion Co-efficient and initial concentration. Chlorinator was filled with bleaching powder and sand mixture and water was added drop by drop so that pot completely filled with water. This amount of water was 11.2 cm^3 in 22.45 cm^3 volume of Chlorinator. The initial concentration in mg/l was determined by
$$\frac{\text{Source concentration} \times 1000}{11.2}.$$

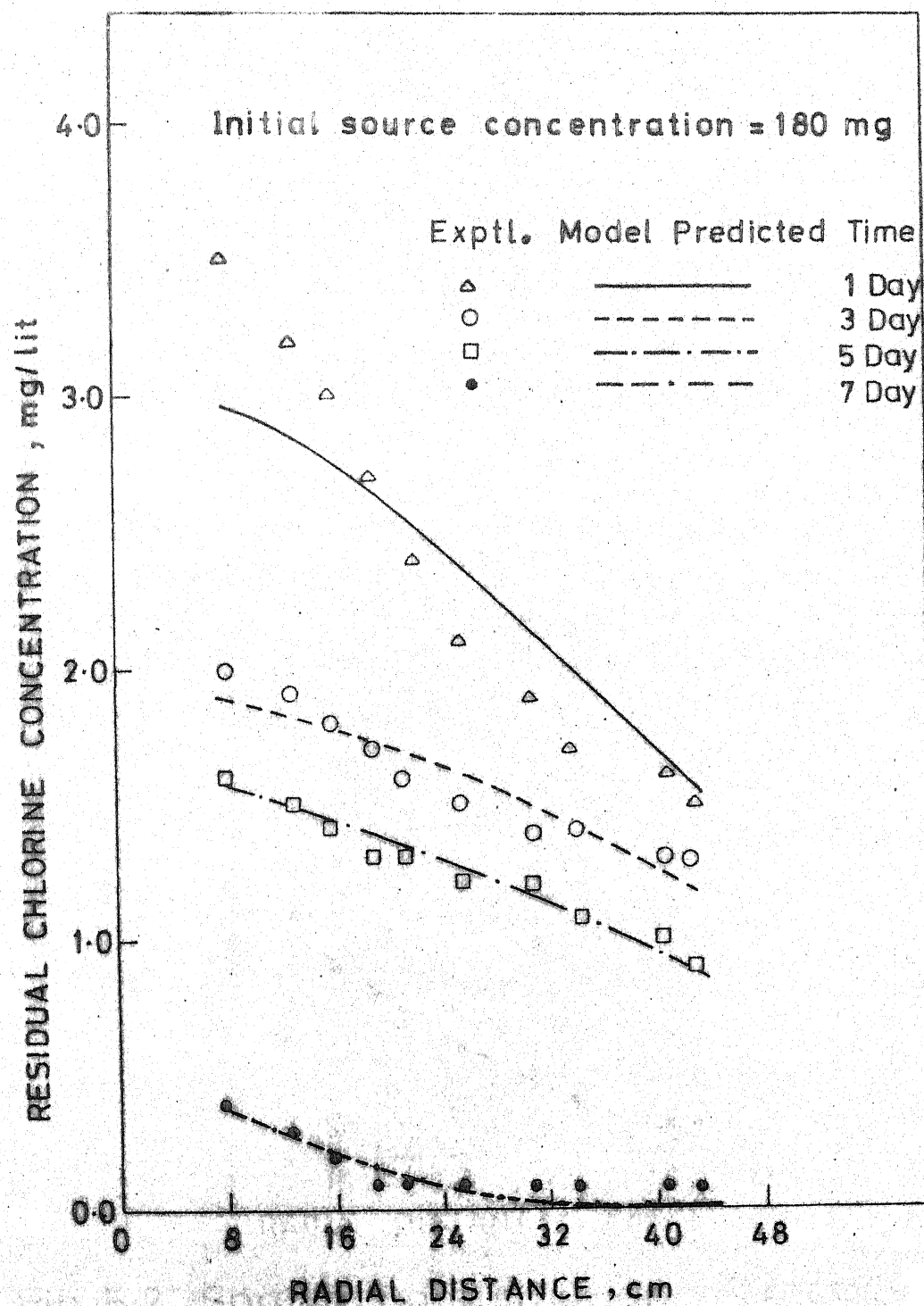


Fig.5-1 Spatial distribution of chlorine in experimental well

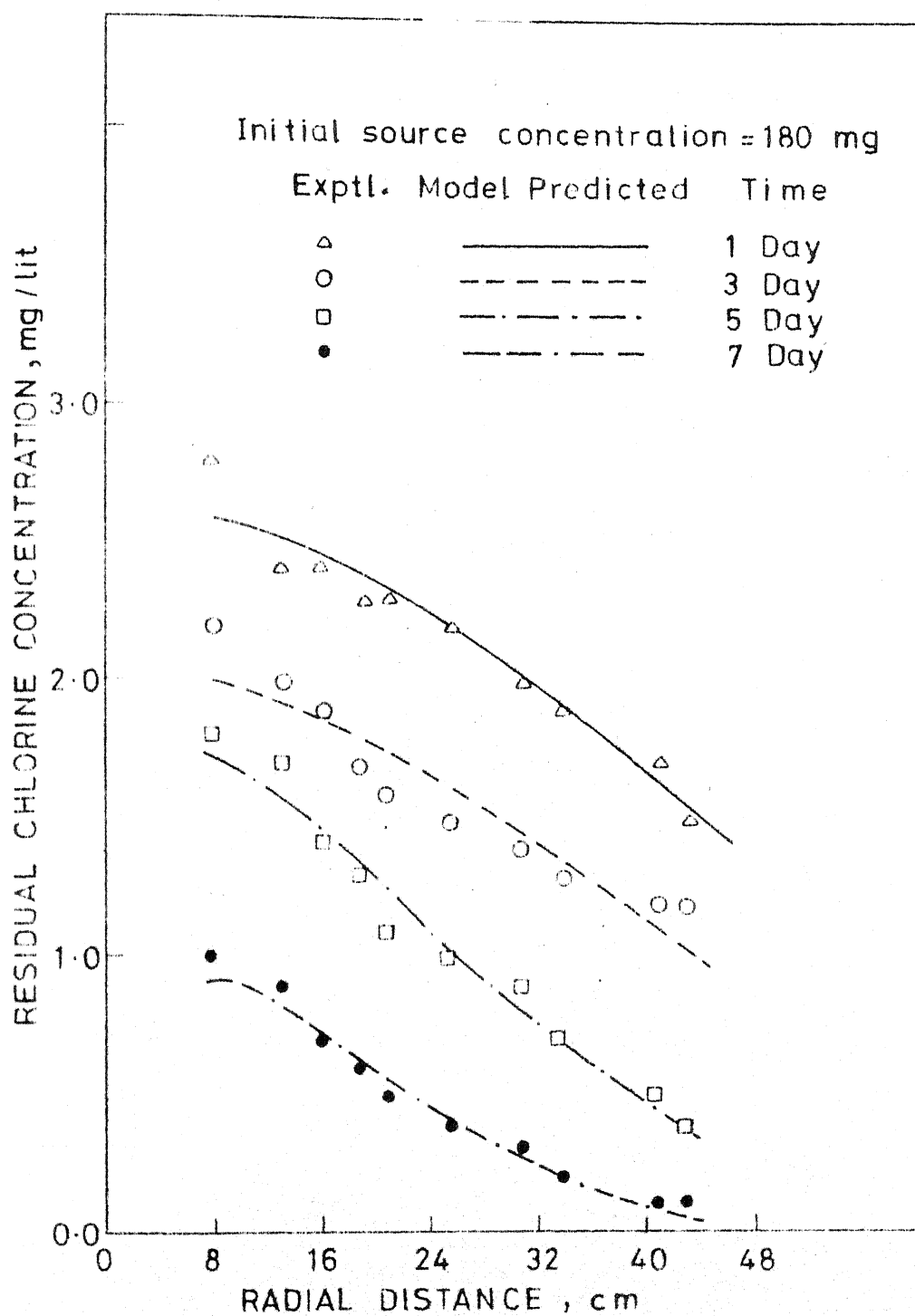


Fig. 5.2 Spatial distribution of residual chlorine in experimental well

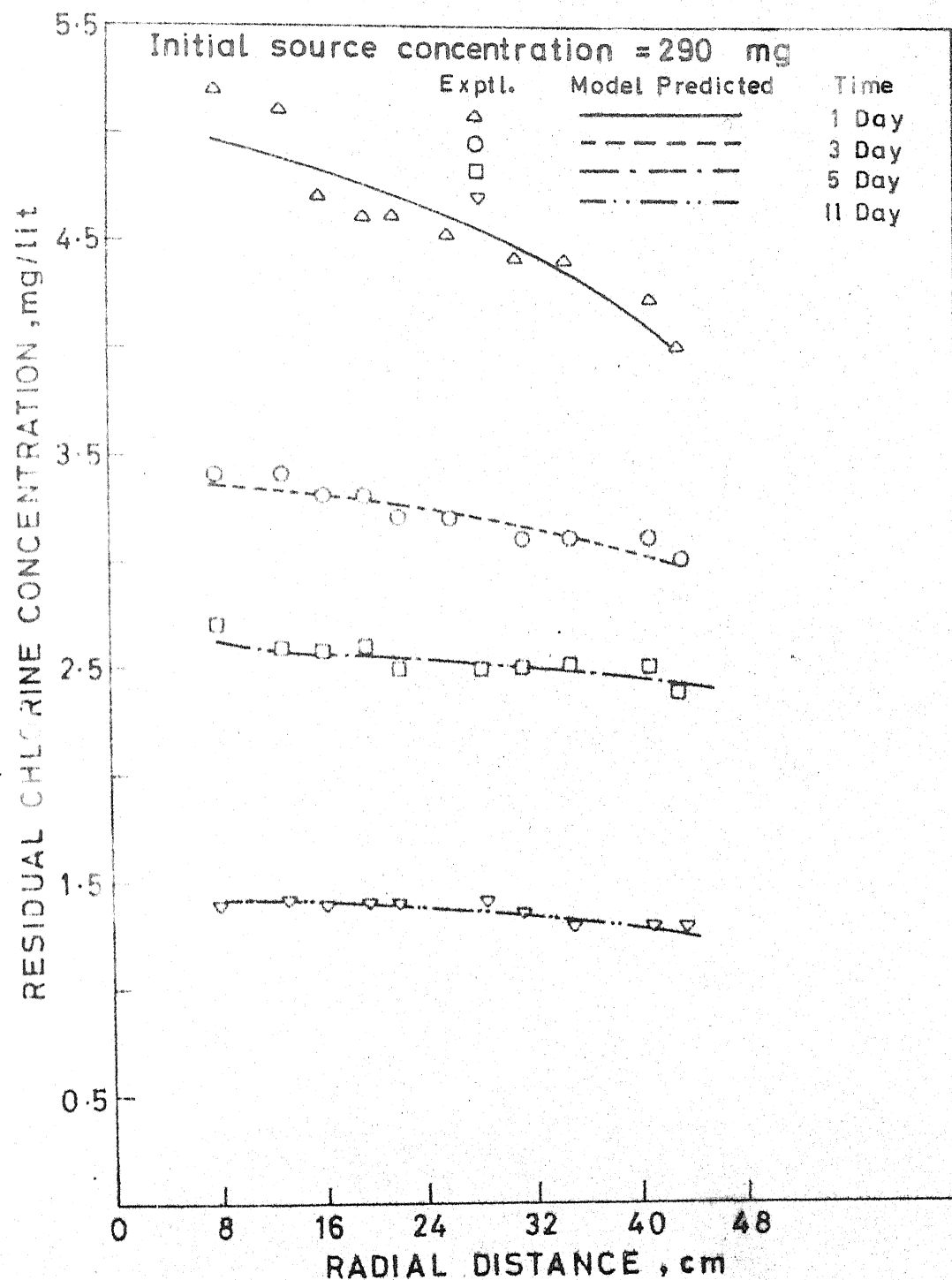


Fig. 5.3 Spatial distribution of residual chlorine in experimental well.

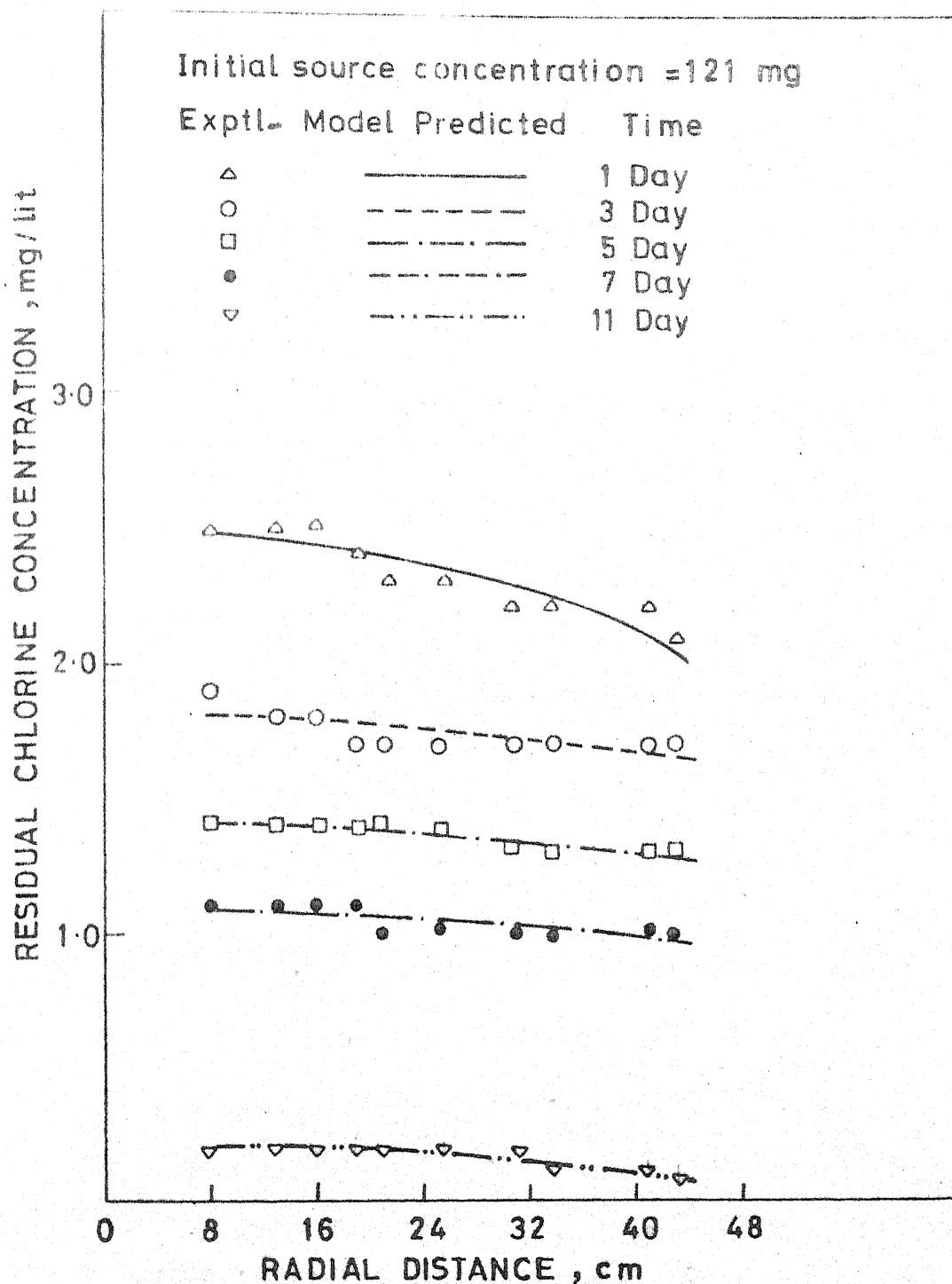


Fig. 5.4 Spatial distribution of residual chlorine in experimental well

In Fig. 5.5, diffusion co-efficient was high for high concentration. Then, it was tried to find the equation of the curve. Taking general equation, $D = S^A e^{BS^C}$, the values of A, B and C were calculated by Computer. The final equation was

$$D = S^{0.125} \times 10^{-6} e^{2.74S^{0.215}} \quad (5.1)$$

Where S is source concentration at any time and D is diffusion co-efficient. This curve can directly be used in design of Chlorinator for the well. The maximum limit of available Chlorine was 29700 mg/lit. So, diffusion co-efficient can increase corresponding to this concentration. For design purpose, if diffusion co-efficient is to be high, the initial Chlorine concentration (mg) will be more and the Chlorinator size will be more. If diffusion co-efficient is low, the size of Chlorinator will small, but service time will be less. Other remarkable point is if initial concentration is more than 29700 mg/l, the source will act as continuous source for some time and residual Chlorine will be high at that period.

So, it is desirable to keep the concentration (mg/lit) within certain range by increasing the sand volume. If the amount of pores water will more, the concentration will be in desirable limit. This part will be discussed again in Chapter 6.

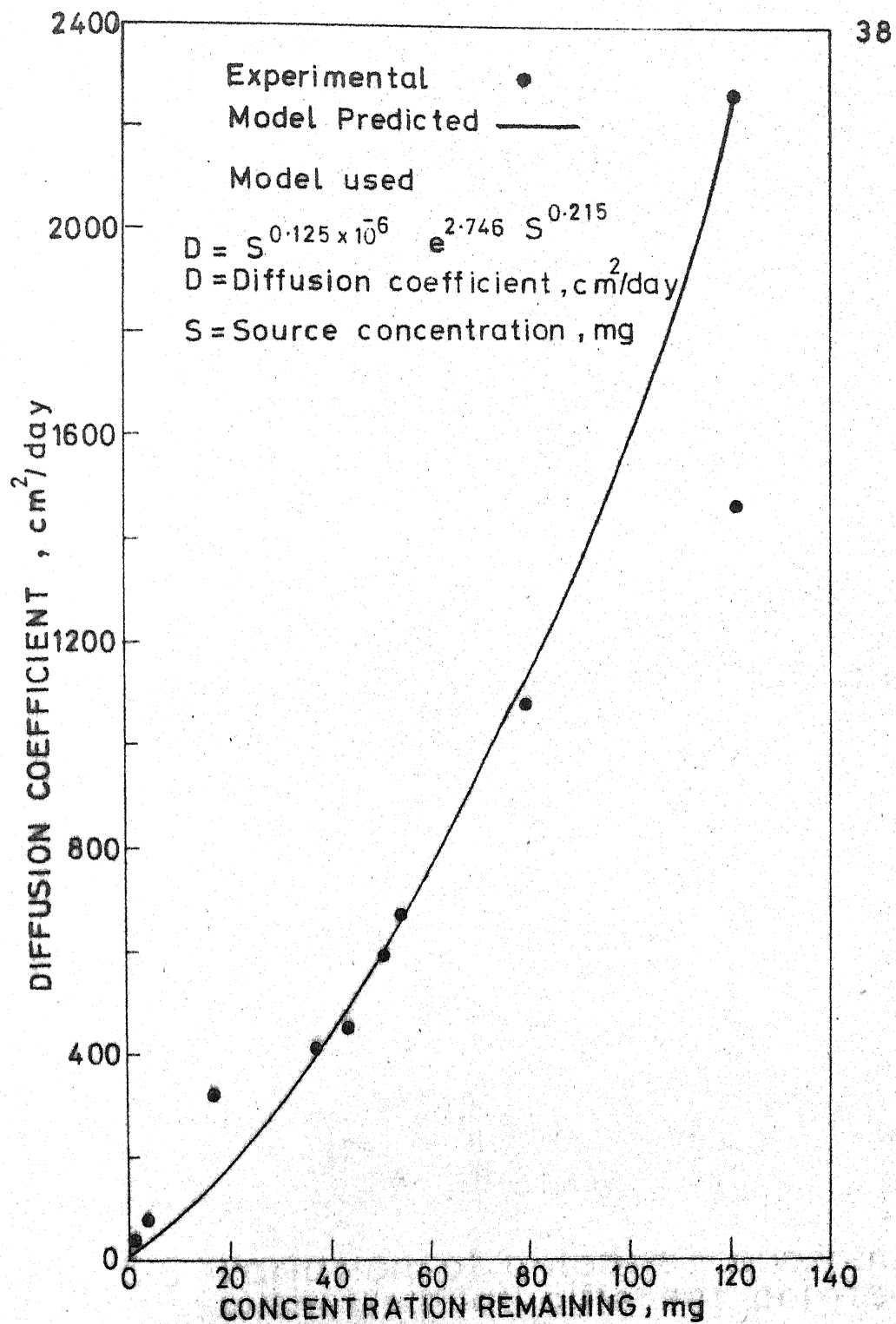


Fig. 5.5 Variation of diffusion coefficient with source concentration

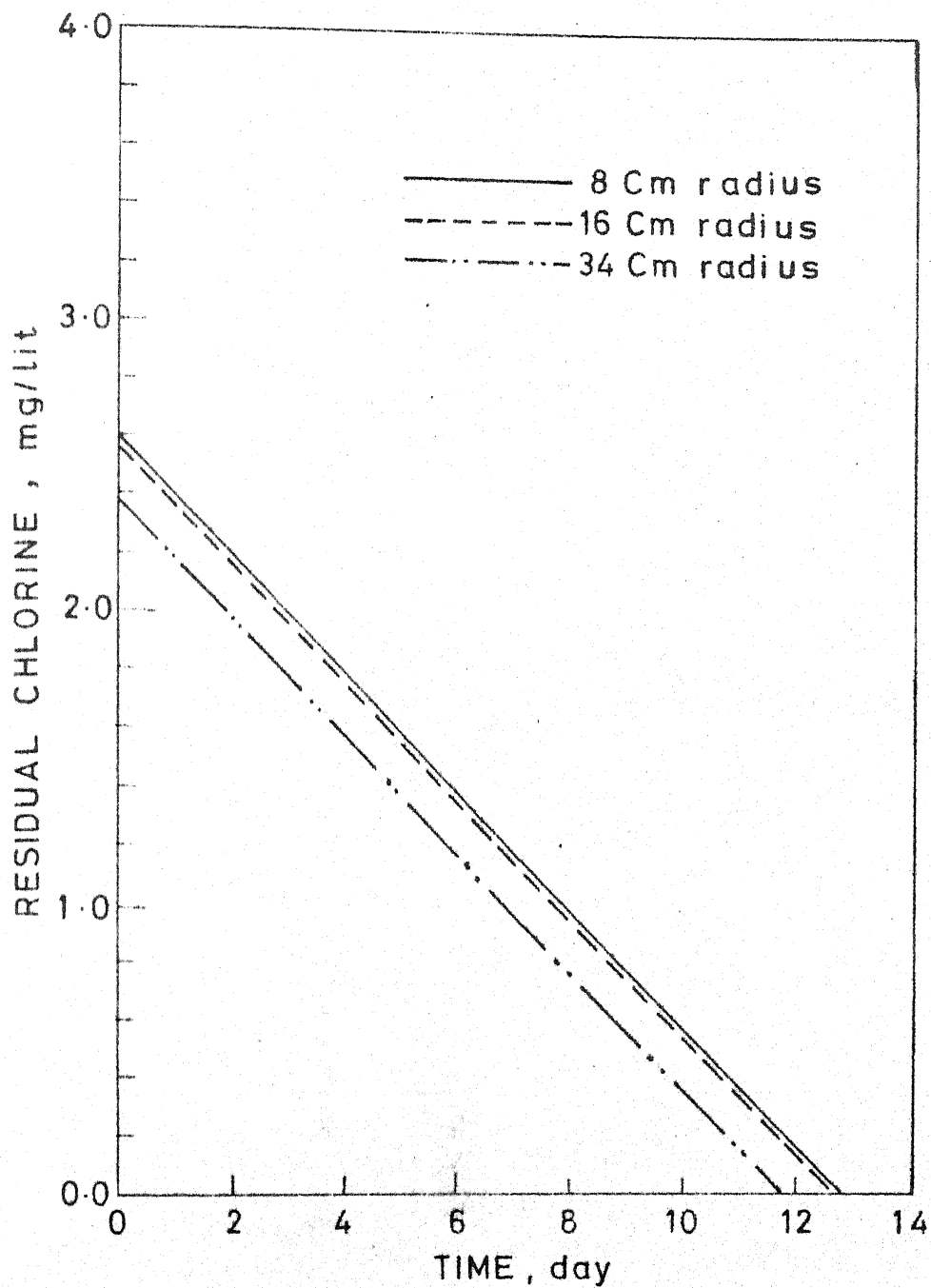


Fig. 5-6 Variation of chlorine concentration with time at different points

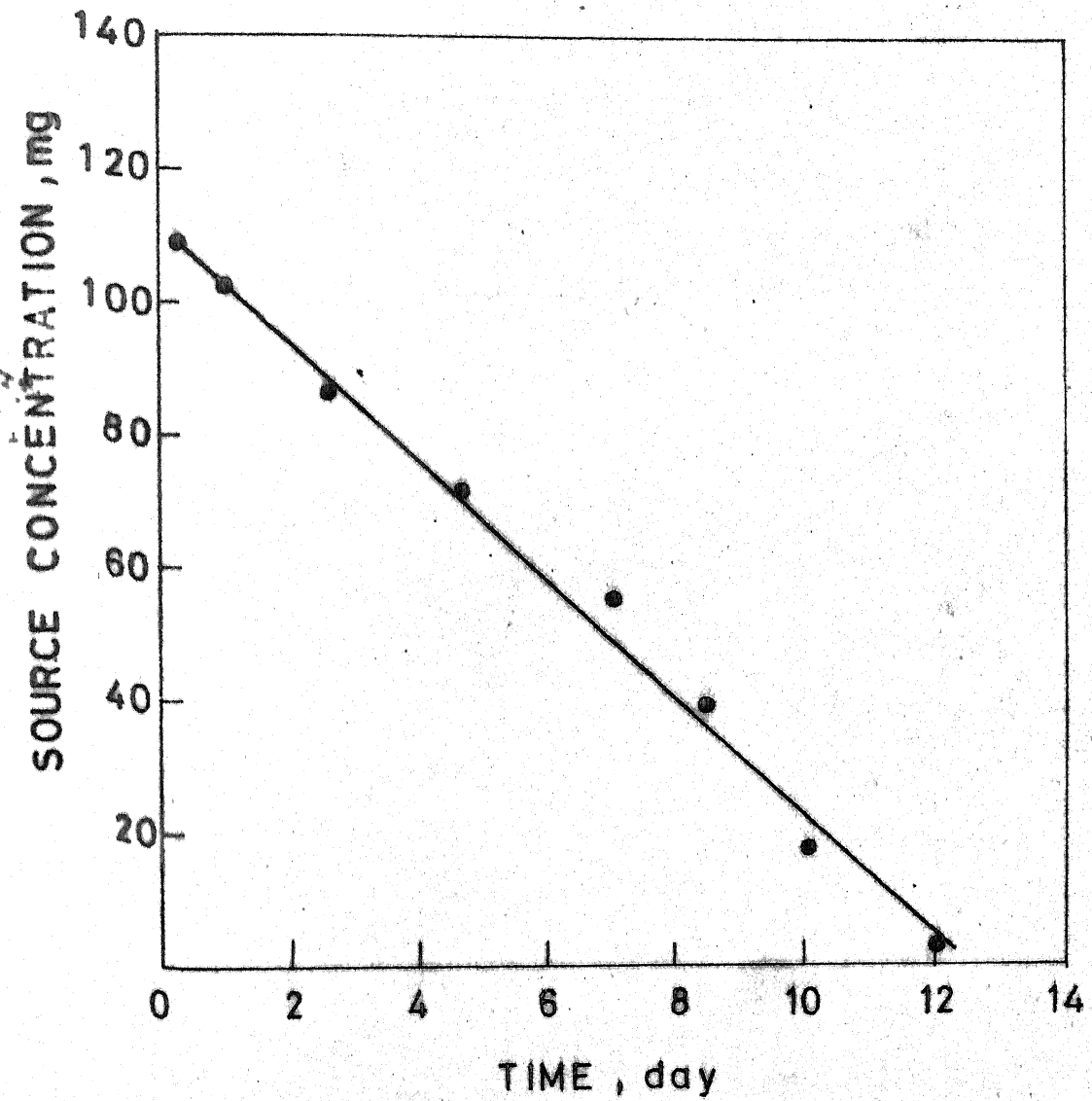


Fig.5.7 Variation of source concentration with time

Fig. 5.6 is the variation of residual Chlorine with time at a point. This gives straight line relationship. The significant of this curve is to determine the duration after which Chlorinator will exhaust. Fig. 5.7 is the variation of source concentration (mg) with time. It is straight line relationship. Initially concentration is high and then, decreases with time. Fig. 5.8 and 5.9 show the predicted residual chlorine in the well using the model.

CHAPTER VI

DESIGN OF CHLORINATOR

6.1 CRITERIA

Based on the verified model, design calculations of Chlorinator are given for a typical well. Fig. 5.5, 5.6 and 5.7 were used as Standard curves for designing the Chlorinator. These curves can be used to design the pot for a well having similar water quality as experimental well used in the laboratory.

In a community well, water generally is with-drawn from about one metre from wall of the well and not more than 1.5 metres depth from the surface. So, water should be safe for drinking in this region. The farthest point under consideration from the centre of well should contain minimum 0.2 mg/lit of residual Chlorine. At the same time it should not contain more than 1.5 mg/lit. So, the residual Chlorine should be 1.5 mg/lit. on first day, it starts decreasing to 0.5 mg/lit.

(1) Bleaching Powder dose: Initial concentration in pot was determined on criteria that the farthest point contained maximum concentration 1.5 mg/lit. by using equation 3.4. The diffusion coefficient was choosen such that the amount of bleaching powder was acceptable quantity. The quantity

of bleaching powder was calculated based on available Chlorine of bleaching powder.

(ii) Chlorinator

The capacity of Chlorinator should be such that it contains total volume of sand and bleaching powder. For the same concentration as experimental well, the water required for completely fill the pores of bleaching powder and sand mixture in the Chlorinator is given by

$$\frac{\text{Chlorine Calculated for actual well (mg)}}{\text{The concentration of experimental well (mg/lit.)}}$$

The Chlorinator used for experimental well had capacity 22.45 cm^3 and the volume of water required for filling the pores of bleaching powder and sand mixture in Chlorinator was 11.2 cm^3 .

So, the porosity is $\frac{\text{Volume of void}}{\text{Total volume}}$ i.e. 0.4989.

Therefore, the volume of Chlorinator = $\frac{\text{Volume of water required}}{\text{Porosity}}$

Then, diameter of pot = $\sqrt[3]{\frac{\text{Volume} \times 6}{\pi}}$

One gram bleaching powder volume with sand was 17.5 cm^3 .

So, the total volume of bleaching powder and sand (1:3) is $17.5 \times \text{Volume of bleaching powder}$.

The volume of Coarse sand of 1.6 mm size = Total volume - Mixture volume.

(iii) Determination of Time

Total time, for which disinfection will continue, are determined by Fig. 5.6. This is a graph between residual Chlorine and time. The difference of day corresponding to 1.5 mg/lit. and 0.2 mg/lit. are the no. of days after which chlorinator will exhaust.

(iv) Design of holes in the Chlorinator

The holes in Chlorinator are designed based on ratio of surface area of well Chlorinator to surface area of experimental Chlorinator and total area of holes in experimental Chlorinator. A typical design is given in next article.

6.2 DESIGN OF CHLORINATOR FOR A TYPICAL WELL:

Diameter of well = 400 cm.

Depth of water = 300 cm.

Daily withdrawal = 5000 Lit.

From equation (3.6), $C = (S/4\pi Dt) \exp^{-\frac{r^2}{4Dt}}$

Taking, $C = 1.5 \text{ mg/lit.}$

$D = 2250 \text{ cm}^2/\text{day}$ and assumed to be constant for a day.

$r = \sqrt{200^2 + 150^2} = 250 \text{ cm.}$

$$S = \frac{1.5 \times 4 \times \pi \times 2250 \times 1}{1000 \times \exp \frac{-250 \times 250}{4 \times 2250 \times 1}} = 43999.8 \text{ mg.} = 43.9998 \text{ gm.}$$

If bleaching powder contains 30 per cent available Chlorine, then, bleaching powder required $= (43.9998/30) \times 100 = 146.666 \text{ gm.}$ For the same concentration, 10803.57 mg/lit., as model Chlorinator the volume of pores water will be $\frac{43.9998}{10.80357} = 4.0727 \text{ lit.}$

In ball of capacity 22.45 cm^2 , the volume of water required to fill the pores of bleaching powder and sand in model Chlorinator is 11.2 cm^2 .

$$\text{So, porosity} = \frac{11.2}{22.45} = 0.4989$$

$$\begin{aligned} \text{So the volume of Chlorinator} &= \frac{4.0727}{0.4989} = 8.16335 \text{ lit.} \\ &= 8163.35 \text{ cm}^2. \end{aligned}$$

$$\text{Diameter of pot} = 3 \sqrt{\frac{8163.35 \times 6}{\pi}} = 24.98 \text{ cm. say } 25 \text{ cm.}$$

Total volume of sand and bleaching powder required = 2.5666 lit.
Remaining volume will be filled with coarse sand of 1.66 mm diameter, Volume required = 5.59668 lit.

Design of holes in pot

$$\frac{\text{Surface area of Chlorinator}}{\text{Surface area of experimental Chlorinator}} = \frac{\text{Area of holes in Chlorinator}}{\text{Area of holes in experimental Chlorinator}}$$

If the number of holes are same as experimental Chlorinator
i.e. 9 holes.

$$\text{The area of holes in Chlorinator} = \left(\frac{25.0}{3.5} \right)^2 \times \frac{9 \times \pi}{4} \times 0.1^2 = 3.6 \text{ cm}^2$$

$$\text{The diameter of hole} = \sqrt{\frac{\text{Area of hole} \times 4}{\pi \times 9}} = \sqrt{\frac{3.6 \times 4}{\pi \times 9}}$$

$$= 0.7136 \text{ cm}$$

Say 7.2 mm

The arrangement of holes are same as experimental Chlorinator.

A big hole of diameter 3 cm is made for charging and
discharging of the mixture of bleaching powder and sand.

A tube is connected in this hole with the help of cork.

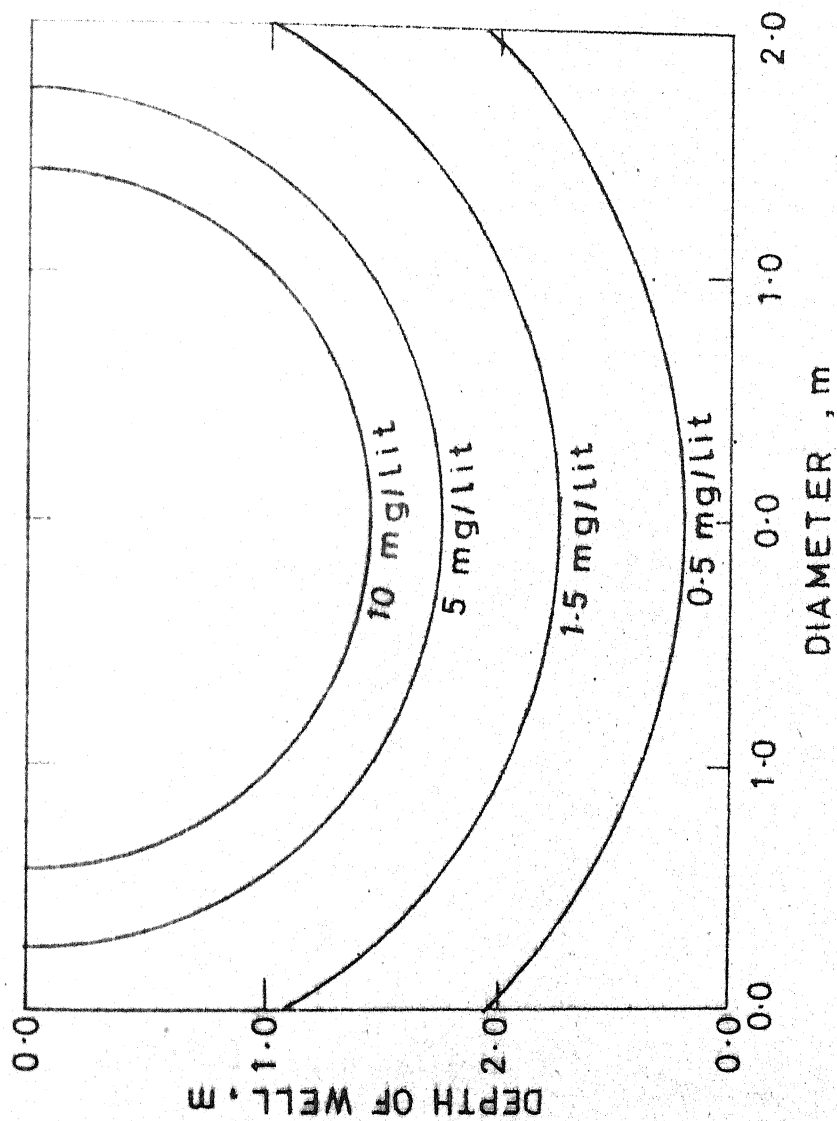


Fig.6.1 Isoconcentration line in well on 0.5 day

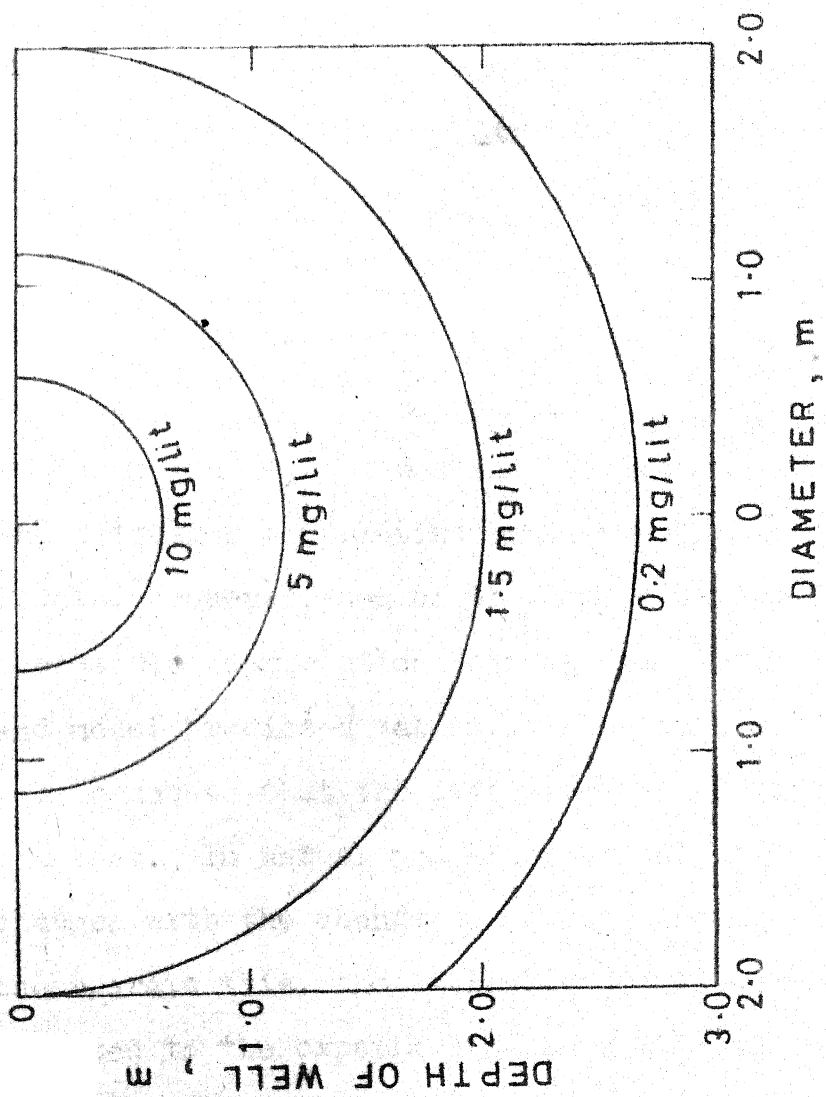


Fig.6-2 Isoconcentration line in well on 9.5 day

CHAPTER VII

SUMMARY AND CONCLUSION

The critical study of the disinfection practice in well waters indicate that pot Chlorinators are gaining more popularity over other methods. However, the present state or knowledge does not lead to any rational design criteria for such chlorinators. Therefore, the present study was carried out with the main objective to develop a rational procedure for the design of pot Chlorinators.

To achieve this objective an experimental well was prepared at the laboratory scale to study the diffusion process. An attempt was made to mathematically represent the diffusion of Chlorine by using available diffusion models. However, none of the available models could give acceptable correlation between experimental observations and model predicted values. This is because of these models assume that the diffusion coefficient remains constant. In actual practice, the diffusion coefficient changes with the change in source concentration. To incorporate this, the available diffusion model was refitted to the experimental data with the assumption that the diffusion coefficient remains constant only for a small duration (0.5 day) in which the source concentration could be assumed at constant level. This

modification gave very good correlation between the experimental observation and model predicted values. The computed diffusion coefficient values were then empirically related to the source concentration, which could predict the values of diffusion coefficient depending upon the concentration of source with reasonable accuracy.

Using the aforementioned modification, a design procedure is outlined to design the pot Chlorinator. The procedure is illustrated by giving calculations for a standard sized well. These computations are checked by predicting the spatial and temporal variation of Chlorine in the actual well. The results indicate that the predicted values are in accordance with the observations made in field.

CHAPTER VIII

SCOPE FOR FURTHER INVESTIGATION

Based on the present findings, it is felt that further work should be pursued in the following areas:

- (i) The experimental well can be modified by placing this in a big container. The space between this well and the container should be filled with sand and enough water. There should be fine holes in the experimental well to simulate natural well condition.
- (ii) Actual determination of concentration of Chlorine at different time intervals in the Chlorinator will help in the calculation of diffusion co-efficient.
- (iii) The experiments should be conducted with cylindrical pot.
- (iv) The effect of number and diameter of holes in the Chlorinator on diffusion co-efficient of Chlorine should be studied to extend this data for practical purpose.

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APPENDIX - A

Experimental Observations - Set No. 1

Initial Chlorine Content - 190 mg, Final Chlorine content - 0 mg, Average Temperature 41°C.

Horizontal distance from Centre (x)		3	8	16	16	8	16	9	16	8	16	
Vertical distance (z)		0	10	0	10	20	20	30	30	40	40	
$r = \sqrt{x^2 + z^2}$												
Radial distance		8.0	12.80	16.0	18.87	21.54	25.61	31.04	34.0	40.79	43.08	
Days		1	2	3	4	5	6	7	8	9	10	11
0		0	0	0	0	0	0	0	0	0	0	0
0.5		0	0	0	0	0	0	0	0	0	0	0
1		1.2	1.0	0.6	0.4	0.1	0.06	0.04	0.02	0	0	0
1.5		2.8	2.3	2.1	1.8	1.4	1.20	0.90	0.60	0.30	0.05	
2.0		3.5	3.2	2.9	2.6	2.4	2.1	1.80	1.40	1.10	0.90	
2.5		2.8	2.4	2.4	2.3	2.3	2.2	2.00	1.90	1.70	1.50	
3.0		2.6	2.4	2.1	1.9	1.8	1.7	1.60	1.60	1.50	1.50	
3.5		2.4	2.2	2.0	1.8	1.7	1.6	1.50	1.50	1.40	1.40	
4.0		2.3	2.2	2.0	1.9	1.8	1.7	1.60	1.40	1.40	1.30	
4.5		2.2	2.0	1.9	1.7	1.6	1.5	1.40	1.30	1.20	1.20	
5.0		2.1	2.0	1.9	1.8	1.7	1.6	1.50	1.40	1.30	1.10	
5.5		1.0	1.9	1.8	1.7	1.6	1.5	1.30	1.20	1.00	0.90	
6.0		1.9	1.7	1.5	1.3	1.1	0.9	0.80	0.70	0.60	0.50	

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Contd. next page.

Contd. Appendix - A

1	2	3	4	5	6	7	8	9	10	11
6.5	1.8	1.7	1.4	1.3	1.1	1.0	0.9	0.7	0.5	0.4
7.0	1.7	1.5	1.3	1.2	1.1	0.9	0.7	0.5	0.4	0.3
7.5	1.5	1.3	1.1	1.0	0.8	0.7	0.6	0.4	0.3	0.2
8.0	1.3	1.1	1.0	0.8	0.7	0.5	0.4	0.3	0.2	0.1
8.5	1.0	0.9	0.7	0.6	0.5	0.4	0.3	0.2	0.1	0.1
9.0	0.7	0.6	0.4	0.3	0.2	0.1	0.09	0.09	0.09	0.08
9.5	0.5	0.3	0.2	0.1	0.1	0.09	0.09	0.08	0.08	0.08
10.0	0.2	0.1	0.1	0.1	0.08	0.08	0.06	0.05	0.04	0.03
10.5	0.08	0.04	0.02	0	0	0	0	0	0	0

APPENDIX-B

Experimental Observation Set No.2

Initial Chlorine Content - 180 mg, Final Chlorine Content - 0 mg Average Temperature = 41°C

Horizontal distance from centre (x)		8	8	16	16	8	16	8	16	8	16	8	16
Vertical distance (z)		0	10	0	10	20	20	30	30	40	40	40	40
$r = \sqrt{x^2 + z^2}$													
Radial distance		8.0	12.80	16.0	18.87	21.54	25.61	31.04	34.0	40.79	43.08		
Days													
0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0
1.0	1.6	1.3	1.0	0.7	0.5	0.3	0.3	0.1	0.05	0.02	0	0	0
1.5	2.6	2.4	2.0	1.9	1.8	1.5	1.5	1.3	1.0	0.50	0.2	0	0
2.0	3.5	3.2	3.0	2.7	2.4	2.1	2.1	1.9	1.7	1.6	1.5	1.5	1.5
2.5	3.1	3.0	2.8	2.6	2.4	2.2	2.2	2.0	1.8	1.8	1.7	1.7	1.7
3.0	2.8	2.6	2.5	2.3	2.1	2.0	2.0	1.8	1.7	1.6	1.5	1.5	1.5
3.5	2.5	2.3	2.1	2.0	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.4
4.0	2.2	2.1	2.0	1.9	1.8	1.7	1.7	1.6	1.5	1.5	1.4	1.4	1.4
4.5	2.0	1.9	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.3	1.3	1.3
5.0	1.9	1.8	1.8	1.7	1.6	1.5	1.5	1.4	1.4	1.3	1.2	1.2	1.2
5.5	1.7	1.7	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.2	1.2	1.2
6.0	1.7	1.6	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.00

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Contd. Appendix - B

1	2	3	4	5	6	7	8	9	10	11
6.5	1.6	1.5	1.4	1.3	1.3	1.2	1.2	1.1	1.0	0.8
7.0	1.4	1.3	1.3	1.2	1.1	1.0	0.9	0.8	0.7	0.6
7.5	1.2	1.1	1.1	1.0	0.9	0.8	0.7	0.6	0.5	0.4
8.0	0.7	0.6	0.6	0.5	0.4	0.3	0.3	0.2	0.2	0.1
8.5	0.4	0.3	0.2	0.1	0.1	0.09	0.09	0.08	0.08	0.08
9.0	0.2	0.2	0.1	0.08	0.07	0.06	0.05	0.05	0.04	0.04
9.5	0.1	0.1	0.09	0.08	0.08	0.06	0.05	0.04	0.03	0.02
10.0	0.03	0.05	0.03	0.02	0	0	0	0	0	0
10.5	0	0	0	0	0	0	0	0	0	0

APPENDIX - C

Experimental Observation - Set No. 3

Initial Chlorine Content - 290 mg, Final Chlorine Content - 0 mg, Average Temperature - 43°00

	8	8	16	16	8	16	8	16	8	16	8	16	8	16	8	16	8	16	8	16
Horizontal distance from centre (x)																				
Vertical Distance (z)	0	10	0	10	0	10	0	10	0	10	0	10	0	10	0	10	0	10	0	10
$r = \sqrt{x^2 + z^2}$	8.0	12.80	16.0	18.87	21.54	25.61	31.04	34.0	40.79	43.08										
radial distance																				
Days	1	2	3	4	5	6	7	8	9	10	11									
0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0.5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1.0	0.8	0.7	0.5	0.4	0.2	0.15	0.06	0.02	0.0	0.0	0									
1.5	3.6	3.5	3.2	3.0	2.8	2.60	2.50	2.40	2.40	1.9	1.7									
2.0	5.3	5.0	4.7	4.7	4.5	4.50	4.40	4.40	4.40	4.2	4.0									
2.5	5.2	5.1	4.7	4.6	4.6	4.60	4.40	4.40	4.40	4.2	4.0									
3.0	4.6	4.6	4.5	4.5	4.4	4.40	4.30	4.20	4.20	4.1	3.9									
3.5	3.9	3.9	3.8	3.8	3.8	3.80	3.80	3.80	3.80	3.7	3.7									
4.0	3.6	3.6	3.5	3.5	3.5	3.50	3.40	3.30	3.30	3.2	3.0									
4.5	3.4	3.4	3.3	3.3	3.3	3.20	3.10	3.10	3.10	3.1	3.0									
5.0	3.2	3.2	3.1	3.1	3.1	3.00	3.00	2.90	2.90	2.8	2.8									
5.5	3.0	3.0	2.9	2.9	2.9	2.90	2.80	2.80	2.80	2.7	2.7									
6.0	2.9	2.9	2.8	2.8	2.8	2.70	2.70	2.70	2.70	2.6	2.5									

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1	2	3	4	5	6	7	8	9	10	11
8.5	2.0	1.9	1.9	1.9	1.8	1.8	1.8	1.7	1.7	1.7
9.0	1.9	1.8	1.8	1.8	1.7	1.7	1.7	1.7	1.6	1.6
9.5	1.7	1.6	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.4
10.0	1.6	1.6	1.6	1.5	1.5	1.5	1.4	1.4	1.4	1.4
10.5	1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3
11.0	1.3	1.3	1.3	1.3	1.2	1.2	1.1	1.1	1.1	1.1
11.5	1.2	1.2	1.1	1.1	1.0	1.0	0.9	0.9	0.9	0.9
12.0	0.7	0.7	0.6	0.6	0.5	0.4	0.4	0.3	0.3	0.3
12.5	0.2	0.2	0.1	0.08	0.08	0.06	0.06	0.04	0.03	0.03
13.0	0.05	0.05	0.05	0.02	0.02	-	0	0	0	0

APPENDIX - D

Experimental Observation - Set No. 4

Initial Chlorine Content - 121 mg., Final Chlorine Content - 0 mg. Average Temperature = 31.00

Horizontal distance from centre (x)		8	16	16	8	16	8	16	8	16	8	16
Vertical distance (z)		0	10	0	10	20	30	20	30	40	40	40
$r = \sqrt{x^2 + z^2}$												
radial distance		8.0	12.80	16.0	18.87	21.54	25.61	31.04	34.0	40.79	43.08	
Days		1	2	3	4	5	6	7	8	9	10	11
0.5		2.7	2.6	2.5	2.4	2.4	2.4	2.3	2.2	2.2	2.1	2.1
1.0		2.5	2.5	2.5	2.4	2.4	2.3	2.3	2.2	2.2	2.2	2.1
1.5		2.3	2.3	2.3	2.3	2.3	2.2	2.2	2.2	2.1	2.1	2.0
2.0		2.1	2.1	2.1	2.1	2.1	2.0	2.0	2.0	2.0	2.0	1.9
2.5		2.0	2.0	2.0	1.9	1.9	1.9	1.9	1.9	1.9	1.9	1.9
3.0		1.9	1.8	1.8	1.7	1.7	1.7	1.7	1.7	1.7	1.7	1.7
3.5		1.7	1.7	1.7	1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.5
4.0		1.6	1.6	1.6	1.6	1.6	1.5	1.5	1.4	1.4	1.4	1.4
4.5		1.5	1.5	1.5	1.5	1.5	1.4	1.4	1.4	1.3	1.3	1.3
5.0		1.4	1.4	1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.3
5.5		1.4	1.4	1.4	1.4	1.4	1.3	1.3	1.3	1.2	1.2	1.2
6.0		1.3	1.3	1.3	1.3	1.3	1.2	1.2	1.2	1.1	1.1	1.0

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1	2	3	4	5	6	7	8	9	10	11
6.5	1.2	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0
7.0	1.1	1.1	1.1	1.1	1.0	1.0	1.0	1.0	1.0	1.0
7.5	1.0	1.0	1.0	1.0	0.9	0.9	0.9	0.9	0.9	0.9
8.0	0.9	0.9	0.9	0.9	0.8	0.8	0.8	0.8	0.8	0.8
8.5	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8
9.0	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
9.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
10.0	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4	0.4
10.5	0.3	0.3	0.3	0.3	0.2	0.2	0.2	0.2	0.2	0.2
11.0	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
11.5	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2
12.0	0.1	0.08	0.08	0.08	0.07	0.07	0.06	0.05	0.05	0.08
12.5	0.05	0.04	0.04	0.04	0.03	0.03	0.03	0.02	0.02	0.02
13.0	0	0	0	0	0	0	0	0	0	0